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# FRICTION STIR WELDING OF ALUMINIUM ALLOYS - A REVIEW

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**ABSTRACT**

*This welding is a novel process used to join metallic alloys. Friction stir welding is in vogue in aerospace, automotive and other industrial establishments for connecting alloys like aluminum, magnesium and copper. Rotational speed, welding speed and the angle of attack are important in the process of FSW. They analyze the weld quality. FSW produces stronger weld joint then the original material in selected parameters. FSW is a solid-state process, where metal is not melted uses a cylindrical shouldered tool with a profiled pin rotated and gradually plunged into the weld joint between two metal parts of plate or sheet that are to be welded together. Frictional heat is produced between the tool and material causing the work parts to soften below the melting temperature, and then physically intermixes the both the metals at the place of the joint, further softened metal due to the high temperature is joined using mechanical pressure applied by the tool. This leaves a solid-phase bond between the two parts. Because temperature below the melting point and joining takes place below the melting temperature of the material, a high-quality weld is created.*

**Key words:** Mechanical Properties, Tool Rotation Speed, Feed Rate, Tilt Angle.

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## INTRODUCTION

It is a method of solid phase welding, which allows a wide range of parts and geometries to be welded are called Friction Stir Welding (FSW), was invented by W Thomas and his colleagues at The Welding Institute (TWI), in 1991. The process proves predominance for welding non-heat treatable to which the fusion welding cannot be applied. Friction stir welding has a wide application potential in aerospace, ship building, automobile and other manufacturing industries. Thus fundamental studies on the weld mechanism, the relation between microstructure, mechanical properties and process parameters have recently been started. Friction stir welding is a relatively simple process as shown in Fig 1. In recent times, focus has been on developing fast, efficient processes that are environment friendly to join two dissimilar materials. The spotlight has been turned on Friction stir welding as a joining technology capable of providing welds that do not have defects normally associated with fusion welding processes. Friction stir welding (FSW) is a fairly recent technique that utilizes a non consumable rotating welding tool to generate frictional heat and plastic deformation at the welding location, thereby affecting the formation of a joint while the material is in the solid state. The rotating tool is pushed against the surface of two overlapping plates. The side of the weld for which the rotating tool moves in the same direction as the traversing direction, is commonly known as the advancing side, the other side, where tool rotation opposes the traversing direction is known as the retreating side.

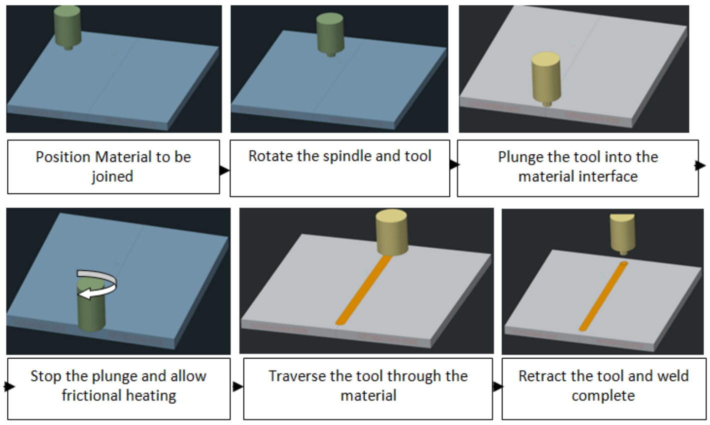


**Figure 1** FSW Principle of Operation

## LITERATURE

Arora et al. [1] states that computed temperatures for maximum shoulder diameter are to the extent of high temperatures normally faced in FSW of AA 6061. Bhatt et al. [2] studied consistent rotational speed of tool and tool of same geometry. Change in the traverse speed of tool has total results on temperature and flow stress in FSW of AA 7050-T7451 aluminium. Biswas et al. [3] have analyzed that concave shoulder and conical pin were preferable to FSW of AA1100 to continue the diameter of the tool pin so tiny as to present a wormhole defect.

Lienert et al. [4] viewed the suitability of FSW of steel to retain its tensile characteristics. FSW of change of tough, HSLA and stainless steels could be possible. The computed results of the analysis made by Nandan et al. [5] shows that significant flow has an effect on movement of heat inside the work piece, the tool rotational and linear movement and lack of symmetry of production of heat around the surface of the tool pin.

The system of FSW and the function of the tool in forming welds in aluminium alloys 7020-T6 were gone into by Kumar et al. [6]. A tool having frustum pin of H13 as hard as 55 HRS was used by them. With a vertical milling machine they performed experiments maintaining consistent welding characteristics which are 140 r.p.m. of the speed of rotation, 80 mm/min of the speed of welding and the angle of tilt $2^o$. It was found by them that while the contact surface of the tool enhances, the defect of the weld gets reduced. They further testified that in the initial part of welding, the shoulder of the tool does not come in contact with the metal to the full extent as a result of which the force around the axis will not be sufficient to generate heat. As such the joint becomes imperfect. The point is that when contact surface between shoulder and metal extends, the force of the axis also enhances. Which the force of the metal will be confined to the cavity of the welds. It will generate enough heat and hydrostatic power. This will ensure a weld that has no fault.

According to Oliver Lorrain et al. [7], threaded pins are used in industrial application. In the initial stages there is a possibility of threaded tools becoming unthreaded. This happens due to the wear of the tool when the toll is used for alloys of a high melting point as well as aluminum alloys that are strengthened. They conducted FSW tests with two variant pin profiles. The two pins are unthreaded with or without level faces. The main idea of this experiment is to study the flow when unthreaded pins are used to weld plates that are thin. To examine the flow of the material welds with cross and longitudinal sections were studied with or without using material marker. Both the threaded and unthreaded pins were observed to process the same material flows. The material is placed in the advancing side in upper portion of the weld which in the retreating side it is placed in the lower portion of the weld with a rotating layer appearing around the tool. This study shows a very low vertical movement towards the weld's bottom due to the absence of threats. The force of the plunge and the speed of the rotation affected the size of the zone controlled by the shoulder. This can be diminished by the use of cylindrical frustum pin having flats.

Numerous studies on transfer of heat and flow of material during FSW were made. Askari et al. [8] employed a 3D finite difference hydrodynamics code to demonstrate the joining of geometry, production of heat and flow of plastic during the process of FSW. The flow of material around the tool was initiated by Zhao [9]. Arbitrary Lagrangian-Eulerian procedures were used by Zhao with a moving mesh to handle extreme plastic distortions around the rotating tool. Using commercial code based fluid dynamic procedures, Colegrove and Shercliff [10] offered a 2D model to study the flow of material around the welding tool.

O F Valero [11] made an attempt to identify the tensile characteristics of the joint performed in different conditions of welding. This study showed the least tensile strength and malleability at the lowest spindle speed for a specific traverse speed. When the speed of the spindle extended, there was increase in strength and elongation attaining the highest point before falling down due to high speed of rotation. In FSW the speed of rotation and the input of heat increase simultaneously. Therefore the speed of the tool rotation must be maximized to achieve the highest tensile of the joints. When the speed of welding rises, the width of the exerted area and the value of the maximum exertion go down. Then the area of the maximum exertion slowly moves to the retreating side of the joint from its advancing side. The tensile strength diminishes considerably as the speed of welding rises. The area which is softened is narrower for higher speeds of welding than for lower speeds of welding. Therefore the

speed of welding must be maximized to obtain maximum tensile characteristics of the FS joints.

Thomas et al. [12] explained the results of microstructure analyses, hardness measurements and tensile tests of Friction stir welded sheets of two aluminium alloys Al Mg4.5Mn0.7 (AA5083) and AlZn6Mg2Cu (AA7075). The macrostructures and microstructures of FSW welds are similar to these produced by hot working. They strongly depend on sheet thickness, as do also their tensile properties. The variation of hardness through weld width is small in alloy AA5083 and more important in AA7075. The strength of FSW welds in AA5083 and AA7075 6.0mm sheets are as high as 100% and 72% respectively of parent material strength.

Z.H. Fu, et al. [13] investigated that Joining by FSW of aluminium is done at low temperature that eliminates the major problem of conventional welding processes, which must be performed under inert gas to present the dissolution of atmosphere gases in the melted material of the joint.

Schmdt and Hattel [14] employed a commercial FE code, ABAQUS, to anticipate an extreme plastic distortion in the process of FSW. To solve coupled thermomechanical problems during the operations of FSW, Nandan et al. [15] prepard a 3D visco-plastic finite element model.

Liu and Fuji [16] discovered that at a low fore of the axis, the shape of non-symmetrical semi-circular units at the top of the weld surface shows mediocre plasticization, through the combination of the material under the sway of the shoulder of the tool, has a proper quality. The structure shear lips and flashes that is extremely high on the advancing as well as retreating sides of the weld line rendering the metal in the area of the weld too thin giving mediocre tensile characteristics, all due to greater force. To prevent this, the force of the axis must be optimized so that optimum tensile characterizes may be obtained.

According to Zaho et al [17] the profile of the pin exercises a crucial role in the flow of the material and thus regulate the welding characteristics of the process of FSW. FSW has a weld lump and flow contour almost round in structure. The flow contour depends on the design of the tool as well as the characteristics and process of welding.

Hidetoshi Fujii [18] studied the effect of the profile of the tool on the mechanical characteristics and microstructures of welded aluminium plates that are 5mm thick. He maintained that the simplest profile without threads and the ordinary profile with threads along with triangular prism shaped profile be used for welding three types of aluminium alloys. For 1050-H24 define to impairment is minimum and a columnar tool without threads produces the weld with maximum mechanical characteristics. In the case of 6061-T6 the power to resist impairment is minimum and the profile of the tool has minimum effect on the microstructures and mechanical characteristics. If the speed of rotation is as low as 600 rpm, the profile of the tool has no notable effect on the microstructures and mechanical characteristics of the joints. P. Cavaliere [19] analyzed the effect of processing characteristics on mechanical and microstructural articles of AA 6056 joints formed by FSW. Many samples were procured by using rotational speeds of 500, 800 and 1000 rpm and welding speeds of 40, 56 and 88 mm/min. The mechanical characteristics of the joints were assessed using micro hardness (HV) and tests of tensility at room temperature.

Sato Y.S. et al. [20] worked on FSW of extremely fine grained Al alloy 1100 provided by stored roll bonding. Friction Stir Welding brought about a repetition of very fine grains in the stir zone and little expansion of the very fine grains of the

ARBed material at the outer surface of the stir zone. FSW has enormous hidden cuts of toughness in the ARBed material, though the stir zone and TMAZ had few cuts of toughness on account of active formation and retrieval. Subsequently, FSW efficiently prohibited the softening in the ArBed alloy.

S. Benavides et al. [21] made a study of minimum temperature FSW of 2024 aluminium. They used active reformation of superfine equiaxed grain forms to make possible super plastic impairment as the welding and unification mechanism.

2024 Al alloy was friction stir welded at an initial heat of 230°C and the maximum heat of the weld zone was within 640°C. The remaining FSW zone grain form had equiaxed fine grains having an identical size of nearly 0.8mm, all though which could be compared with a central weld zone grain of nearly 10 mm in 2024 Al FSW at an initial of 30°C, where the maximum heat was 330°C. A cut is obvious in the softening close to the boundary of the weld one around the weld HAZ when the heat is minimum through no similar softening exists in the weld zone contrary to the room heat of the weld zone. It causes reversal of toughness in similar weld zones.

H.G. Salem [22] used friction stir technology to link actively reconstituted Al alloy light sheets for structural parts fulfil the demand for generation and hardness of macrostructures as well as microstructures. FSW at 1000 rpm speed of tool rotation and 4.2 mm/s weld feeding rate were accomplished without grain growth. FSW in created the fine equiaxed structure with high grain boundary angles.

Fonda R.W. et al. [23] made a study of the growth of grain structure at some stage in friction stir welding. They observed that a stop action FSW was arranged in Al-Li 2195 to free in the active impairment area adjacent to FSW tool. An examination of a plan view section of the weld shows important new information of evolution of the structure of grain and the development of the texture near the FSW tool. Strips of grain develop in front of the fully polished area showing divergent stabilities of the earlier grain adjustments to the applied impairment. Polished sub-grains develop in the area of impairment and slowly develop higher disorientations to bring about finer grains as noticed near the tool. This area shows an fcc shear texture following application of appropriate rotations. Thus in this weld the main process of purification of grain is the subdivision caused by impairment and active retrieval processes. There is no need to evoke an active restructuring process.

Liu G. et al. [24] studied the microstructural issues of FSW of 6061-T6 aluminium and stated that LM and TEM were used to describe the microstructures in the FSW area and compare these microstructures with the primary 6061-T6 aluminium alloy plate which was about 0.65 cm in thickness. They calculated the profile of microhardness stretching from work piece and through zone of the weld. They also conducted many butt and assumed welds in stable plate divisions at the speeds of rotation extending from 300 to 1000 rpm and traverse speeds of 0.15 to 0.25 cm/s. The tempered carbon steel welding head pin was 0.63 cm in diameter and 58 cm/s long. The main results that were obtained were that the FSW area in 6061-T6 aluminium was represented by an active and continuous restructuring of microstructure. The particles in the next phase of the work piece are stirred into the weld area where the remaining toughness varies from 55 VHN near the bottom of the weld. These contracts with the toughness of the work piece varying from 85 and 100 VHN. The size of the weld area grain had an average of 10 μm as against 100 μm of the work piece.

A constantly rotated non consumable cylindrical tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped parts of

butted material. The pin is slightly shorter than the width of the weld metal, with the tool shoulder riding atop the work surface. Frictional heat is generated between the wear resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material.

**Metallurgical benefits:** less distortion, high stability, fine microstructure

**Environmental Benefits:** Shielding gas not required

**Energy Benefits:** less energy required

## MICROSTRUCTURE

Due to high plastic deformation and high temperature in the stirred zone during FSW recrystallization and microstructure evolution occurs in stirred zone and precipitate dissolution and coarsening within and around the stirred zone. On the basis of microstructural characterization of grains and precipitates, three different zones, Nugget (stirred) zone, thermo-mechanically affected zone (TMAZ), and heat affected zone (HAZ) have been identified. The microstructural variations in different zones have considerable effect on post weld mechanical properties

## CONCLUSION

The friction stir welding is very recent trends in the manufacturing technology of metal joining processes especially for aluminum alloys. It is found that many research works are done on the aluminum alloys. Moreover various engineering industries will not only give importance for aluminum and aluminum based alloys but also for mild steel and its alloys. This paper highlights the principle of FSW and vital factors that influence the quality of weld and the critical analysis realize the possible research works on other than aluminum alloys such as mild steel etc.

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